The Journal of Transport and Land Use http://jtlu.org
Vol. 12 No. 1 [2019] pp. 785–810

JTLU

Workplace location, polycentricism, and car commuting

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Abstract: Although significant strides have been made regarding the relationship between urban structure and travel, some doubt appears to be lingering concerning the impacts of polycentric urban development. For example, the debate on whether a polycentric or monocentric workplace location pattern is favorable for reducing negative environmental effects from transportation has not been entirely settled. This study intends to contribute to clearing up some of the misconceptions by focusing on the implications of spatial distribution of jobs on commuting patterns among employees within the Oslo metropolitan area. Results show a strong tendency for a higher share of car commuting among employees working in suburban workplaces. This pattern persists also for suburban workplaces located close to suburban transit nodes. The share of transit commuters shows the opposite pattern. Commuting distances also tend to increase the farther from the city center the workplace is located. These conclusions are based on cross-sectional and quasi-longitudinal survey data as well as semi-structured in-depth interviews of workers, including several interviewees who had changed their workplace locations. To our knowledge, this is the first mixed-methods study on the influence of workplace location on commuting behavior. The results raise doubt about the appropriateness of polycentric intra-metropolitan workplace development as a strategy for sustainable mobility.

Article history:
Received: November 7, 2018
Received in revised form: March 4, 2019
Accepted: October 3, 2019
Available online: November 7, 2019

1 Polycentric workplace location—a measure to solve traffic problems in urban areas?

The purpose of this paper is to illuminate how the intra-metropolitan location and neighborhood characteristics of workplaces influences commuting distances, commuting travel modes and travel time for commuting. Using the Oslo metropolitan area in Norway as a case, the paper draws on a mixed-methods study combining a tailor-made survey among employees of 14 workplaces with qualitative interviews of some of the respondents. To our knowledge, this is the first mixed-methods study of the

http://dx.doi.org/10.5198/jtlu.2019.1488
ISSN: 1938-7849

The *Journal of Transport and Land Use* is the official journal of the World Society for Transport and Land Use (WSTLUR) and is published and sponsored by the University of Minnesota Center for Transportation Studies.

influence of workplace location on commuting behavior. The paper is based on the quantitative part of the study. Another paper (Næss, Tønnesen, & Wolday, 2019a) presents the qualitative part of the same study, where we conducted in-depth interviews with 13 employees of workplaces differently located within the metropolitan area. The latter paper and the present one are meant as "companion papers." By uncovering reasons given and underlying rationales and conditions that can explain the aggregate-level patterns, the qualitative interviews augment the quantitative findings. The purpose of this paper is to illuminate how the intra-metropolitan location and neighborhood characteristics of workplaces influences commuting distances, commuting travel modes and travel time for commuting.

A central debate on development of urban regions centers around questions of where to locate businesses, services, workplaces and dwellings. In much of the literature on urban land-use planning conducive to sustainable mobility there has been a focus on developing dwellings and workplaces close to public transport nodes, often quite distant from city centers. This is reflected in urban planning concepts such as "transit-oriented development" and partly also in policy discourses on polycentric urban development (see, e.g., Davoudi, 2003).

There is no widely accepted definition of polycentricity. Different actors and disciplines define the concept differently. For example, in law science, polycentricity may refer to a situation where providers of legal systems compete or overlap in a given jurisdiction (Bell, 1999), whereas in urban and regional planning it may refer to the distribution of population, jobs and/or service facilities over a geographical area. In addition to the normative use of the concept, polycentricity means different things when applied to different spatial scales (Davoudi, 2003). For example, does the concept refer to a pattern of individual cities at a national scale, within a larger region, or to a pattern of centers within the individual city (Jensen & Richardson, 2004)? Useful for this paper is Garcia-López's (2010) description of the polycentric model. This model implies a decentralized concentration in contrast with the dispersed model where outskirt land take is fragmented and characterized by sparsely populated settlements. Relating this to the context of Oslo, polycentrism would mean concentration of development in regional smaller cities around the capital, instead of a more scattered development. This is emphasized in the regional land-use and transport plan for Oslo and the neighboring county of Akershus, explicitly stating goals of spatial effectiveness and planning based on polycentric principles (Municipality of Oslo/County of Akershus, 2015).

The Norwegian government has seen polycentric development as a tool to reduce pressure on the larger cities (Ministry of Transport, 2013). At the heart of this strategy is compact development around nodes offering high-quality railway services. A resembling approach is found in the metropolitan planning of the Copenhagen region. Here, the so-called the "finger-plan principle", with traces back to 1947, is part of the mainstream planning doctrine (Davoudi & Sturzaker, 2017). Concentration of urban growth in "fingers" and close to public transport nodes, is highlighted both to strengthen transit and to preserve green corridors in suburban areas (Danish Business Authority, 2017).

Looking again at the Oslo region, the regional plan emphasizes the need for more specialized workplaces outside the core city. Especially, the plan argues, better balance between workplaces in Oslo and in regional cities in Akershus will contribute to better directional balance and better utilization of the transport system (Municipality of Oslo/County of Akershus, 2015, p. 39.) This illustrates how regional-development arguments are entwined with those of traffic management. However, to support sustainable mobility this will require the "opposite-direction capacity" of trains and buses to be utilized, not the capacity of highways to accommodate more cars.

Further, the Oslo-regional plan argues that polycentric development could shorten travel distances: "More high-competence workplaces [north and southeast of Oslo] can give shorter commutes and a broader labor market for more [people]" (Municipality of Oslo/County of Akershus, 2015, p. 13). This resonates with the quite widespread belief that employees at suburban workplaces would on average enjoy shorter commuting distances than those of centrally located jobsites.

There are studies showing that residents in neighborhoods with high availability of local jobs tend to commute shorter distances and drive less than those in neighborhoods with a deficit of jobs. However, this does not necessarily mean that commuting distances and car driving are reduced at a metropolitan scale (Næss, 2011; Aguilera & Voisin, 2014) or that these effects are maintained over time. Duarte and Fernández (2017) point to that while studies may show how sub-centers allow population living around them to have shorter commuting, this is not necessarily so if analyzing data from a diachronic perspective. Their argument rests on studies showing how the capacity of sub-centers to retaining working population and satisfy labor demands of localized firms is reduced over time. Given the many factors influencing recruitment and selection of workplace, important questions revolve around the likelihood for a suburbanite to be employed at a local suburban workplace.

Against this background, the paper aims to illuminate the following research questions:

- How does the location of the workplace relative to the main metropolitan center and lower order centers, respectively, influence the distance, travel mode and time spent on commuting?
- How do local neighborhood characteristics of the workplace influence commuting behavior, and how do such characteristics relate to the location of the workplace relative to the overall metropolitan center structure?
- Is polycentric workplace development in a predominantly monocentric urban region such as Oslo a viable strategy for achieving sustainable mobility?

The next section (2) presents theoretical perspectives and experience from earlier studies on the links between workplace location and commuting. Thereupon, the case region will be presented (Section 3), followed by a presentation of the research design and methods of the study. Section 5 presents the quantitative results of the study. Drawing on the qualitative material, Section 6 presents underlying motivations and rationales that can explain the aggregate patterns, followed by a discussion (Section 7). Some brief concluding remarks round off the paper (Section 8).

2 Theoretical considerations and literature review

2.1 Theoretical considerations

In many urban regions, population densities are higher in the inner than in the outer part of the region (Alonso, 1960; Bertaud, 2003; Clifton, Ewing, & Song, 2008), which is also the case in Oslo metropolitan area (Næss, Strand, Wolday, & Stefansdottir, 2019b). This contributes to on average shorter commuting distances among employees of inner-city workplaces. Office workplaces are often highly specialized (in terms of education and prior professional experience), recruiting employees from a large population base. Workplaces within retail, primary education, kindergartens, health care etc. are often less specialized and hence more able to recruit employees locally.

There are also important differences in how accessible centrally located and suburban workplaces are with different modes of travel. A crucial factor influencing the modal choice of car-owning commuters is the travel time ratio (measured door-to-door from home to workplace) between car and alternative modes of travel (Mogridge, 1997). Since walking time from the public transport stop to the workplace often makes up a considerable part of the total door-to-door travel time when commuting by public transport, workplace location close to public transport stops will, other things being equal, increase the likelihood for commuters to choose transit as their travel mode.

There is, however, considerable variation in the level of public transport service offered by different public transport stations. Jobs at nodal stations can be reached from several directions without having to change between different transit lines, whereas non-nodal stations only offer this possibility for those commuters who live along the transit line passing the workplace (Allpass, Ågergard, Harvest, Olsen, & Søholt, 1967). The frequency of departures also matters. If the intervals between departures are long, the public transport offers a low level of flexibility, and especially if the working hours are fixed, such inflexibility can represent considerable "hidden waiting time." In most cities, the public transport network is characterized by radial trunk lines from the city center to the suburbs, supplemented with a limited number of ring lines and feeder bus lines. The city center is therefore the major node, which can be accessed from locations along all the radial lines without having to transfer from one line to another. Moreover, in most cities, there is also a center-periphery density gradient of both residences and workplaces (Bertaud, 2003; Clifton et al., 2008), which means that the population base for a high frequency of departures will normally be higher in the inner than in the outer parts of a city or an urban region.

In addition, the accessibility by car is normally higher in the outer suburbs than in the inner districts of the city. Congestion and scarcity of parking space in downtown areas may cause a number of potential car commuters to leave their car in the garage at home. Distinct from this, suburban jobs are often poorly accessible by transit, while access by car is easy with less congested roads and usually ample parking (Hess, 2001). Combined with the normally far better access by public transport to centrally located workplaces than to suburban or exurban jobs, this implies that the travel time ratio between car and transit is much more favorable to public transport for inner-city workplaces than for workplaces located close to public transport stops in the outskirts of the city or metropolitan area. Thus, as theorized by Allpass et al. (1967), the city center is therefore the part of the urban region where transit accessibility is normally at its highest and car accessibility is at its lowest.

Inner-city job locations also have an advantage to low-density suburban locations in terms of facilitating non-motorized journeys to work. This is partly due to the above-mentioned worse conditions for car driving, and partly due to the normally higher number of potential employees living within acceptable walking or biking distance if the workplace is located in the inner-city than for job locations in the outer parts of the city/metropolitan area.

Figure 1 summarizes the above-mentioned mechanisms that could all, from theoretical considerations, lead to higher expected shares of car commuting to peripherally than to centrally located workplaces (and conversely to higher shares of commutes by public transport to inner-city workplaces than to workplaces located in the outer districts of the city/metropolitan area). Notably, the location of the workplace within the region influences local-scale characteristics such as transit level of service and parking supply at the workplace, and not the other way around. This means that it would be incorrect to include the latter variables as control variables without including the indirect effects of the distance from the city center via these variables.

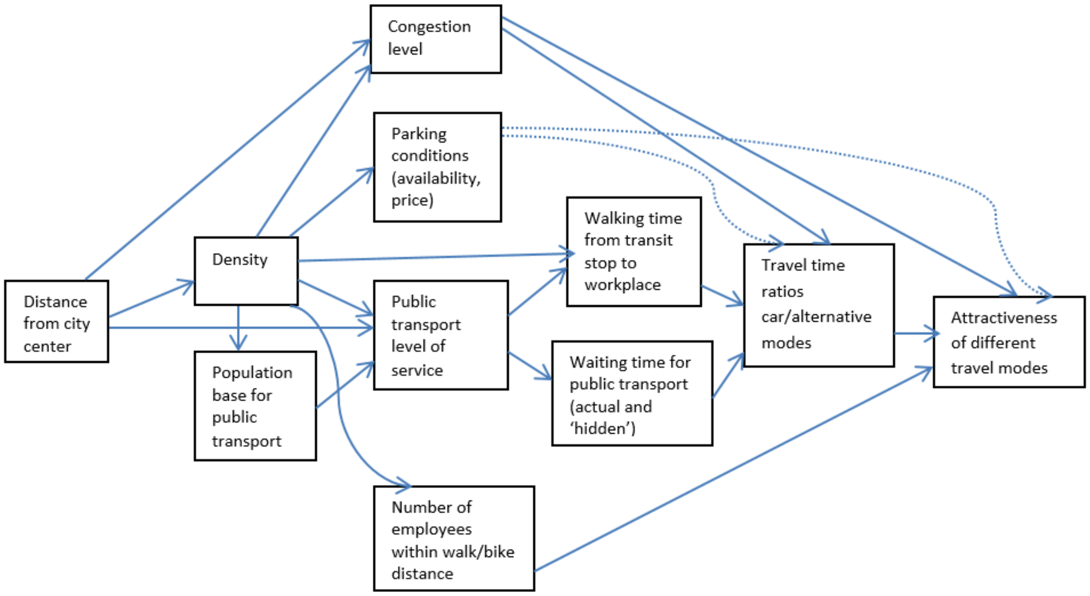

Figure 1. Mechanisms contributing to different modal shares for commuting trips to central and peripheral workplaces
Source: Our own work.

Relevant to the discussion about monocentric versus polycentric workplace development, we have focused on the following urban structural characteristics of the workplace: distance from the workplace to the main city center, and to the closest second-order center, and combined population and job density in the local area of the workplace. Our choice of variables thus differs from the widespread framing of urban structural variables in a scheme of a number of D's (Cervero & Kockelman, 1997; Cervero, Sarmiento, Jacoby, Gomez, & Neiman, 2009), which tends to direct the research interest toward local-scale rather than city- or metropolitan-scale built environment characteristics. We have carried out an additional analysis focusing particularly on the local scale to investigate the role of jobs-housing balance in the local area of the workplace and transit accessibility to the workplace.

2.2 Earlier empirical studies

Some studies (particularly in the United States) have found employment deconcentration to reduce commuting distances (Crane & Chatman, 2003; Guth, Holz-Rau, & Maciolek, 2009). Similarly, Cervero and Duncan (2006) found that local jobs-housing balance in the suburbs (within 4 km from the dwelling) would contribute to reduce driving. However, other studies in USA and Europe conclude that job decentralization from inner to outer parts of cities and metropolitan areas does not contribute to reducing average commuting distances (Cervero & Landis, 1992; Yang ,2005; Aguiléra, Wenglenski, & Proulhac, 2009; Hu & Schneider, 2017). Recently, Vale, Pereira and Viana (2018) found that the staff and students of inner-city campuses in Lisbon lived on average closer to their university than the staff and students of suburban campuses did.

Several Nordic studies have found somewhat increasing commuting distances to office workplaces the more peripherally the jobs are located (Hartoft-Nielsen, 2001, in Copenhagen; Strømmen, 2001, in Trondheim). In a later study in Copenhagen metropolitan area, the commuting distances of employees with an education level below the median was found to increase the closer the workplace was located to the city center, whereas an opposite tendency was found among those with education above the median. In total for all types of workplaces, the longest mean commuting distances were found among employees working some 10–25 km from the city center, with shorter commutes among those working more centrally as well as those working in the outermost parts of the metropolitan area (Næss, 2007). A similar pattern was fund in an older study in Helsinki (Martamo, 1995). A recent study of the four largest Norwegian cities (Engebretsen, Næss, & Strand, 2018) showed increasing commuting distances the farther away from the city center the workplace was located in Oslo, Bergen, Stavanger/Sandnes as well as in Trondheim. This study was confined to the continuous urban area of each city, and any declining tendency for workplaces in the outer parts of the metropolitan area was thus not covered.

Studies in the Nordic countries as well as elsewhere in the world have found lower proportions of car commuting and higher shares of travel by public transit, bicycle or by foot to workplaces located in the inner-city than to suburban jobsites. The Nordic cities and metropolitan areas where such patterns have been found include, among others, Oslo (Monsen, 1983; Hanssen, 1995, Næss & Sandberg, 1996; Næss et al., 2019b; Engebretsen et al., 2018); Helsinki (Martamo, 1995); Copenhagen (Hartoft-Nielsen, 2001; Næss, 2007; Hartoft-Nielsen & Reiter, 2017), Trondheim (Strømmen, 2001); Stavanger (Næss et al., 2019b; Engebretsen et al., 2018) and Bergen (Engebretsen et al., 2018). In particular, a strong center–periphery gradient has been found for office workplaces. In a wider international context, similar patterns have been found in Melbourne (Bell, 1991); the San Francisco Bay area (Cervero & Landis, 1992); London and other large British cities (Dasgupta, 1994); the Dutch Randstadt area (Schwanen, Dieleman, & Diest, 2001); Atlanta and Boston (Yang, 2005); the Paris region (Aguiléra, Wenglenski, & and Proulhac, 2009; Aguiléra & Voisin, 2014), Chicago metropolitan area (Hu & Schneider, 2017); Luxemburg (Sprumont & Viti, 2018) and Lisbon (Vale, 2013; Vale et al., 2018).

The majority of earlier studies of workplace location and travel are based on cross-sectional data. Some studies have investigated effects of workplace relocation by comparing average modal shares and commuting distances among a company's employees before and after relocation (Monsen, 1983; Bell, 1991; Hanssen, 1995), or by analyzing aggregate-scale (e.g., metropolitan) changes over time in job locations and commuting behavior (e.g., Gordon, Kumar, & Richardson, 1989; Gordon & Lee, 2015). Quite few earlier studies have investigated changes in commuting behavior among individuals who have recently changed their workplace location (Cervero & Landis, 1992; Hanssen, 1995; Vale, 2013; Sprumont & Viti, 2018). To our knowledge, no previous studies of influences of workplace location on commuting have included qualitative interviewing.

3 The case city region

Oslo is the capital city in Norway and the administrative-, knowledge- and finance center. Like many western cities, Oslo has experienced deindustrialization. Within the municipal border there are 681,000 inhabitants (Statistics Norway, 2019a), while 1,000,500 inhabit the continuous urban area of Oslo, which stretches into eleven neighboring municipalities (Statistics Norway, 2019b). From 2016 to 2017 the Municipality of Oslo experienced a population growth of 1.3 percent, and between 2013-17 a 7 percent increase. Despite this growth, land take has been low, illustrating a tendency of urban densification. The Oslo metropolitan area has a predominantly monocentric/hierarchical urban structure, with downtown Oslo as the main center, supplemented with a limited number of second-order centers and many local centers. Oslo's population density (37 persons per hectare within the continuous urban area in 2018) is lower than in a large European city such as Berlin (54 pers./hectare in 2005), but considerably higher than in US cities such as San Francisco and Washington, with 19 and 13 persons per hectare, respectively (Statistics Norway, 2019b; Kenworthy & Inbakaran, 2011). Compared to American cities, Oslo has an extensive network of transit services (metro, streetcar and bus lines as well as commuter trains), with a high level of service particularly in the inner parts. Parking is scarcer and more expensive in the downtown area. Toll cordons around the inner city and Oslo's municipal border have an additional, yet not very strong, deterrent effect on inward car commuting.

Figure 2 shows how job and population densities, respectively, vary between different parts of Oslo metropolitan area.

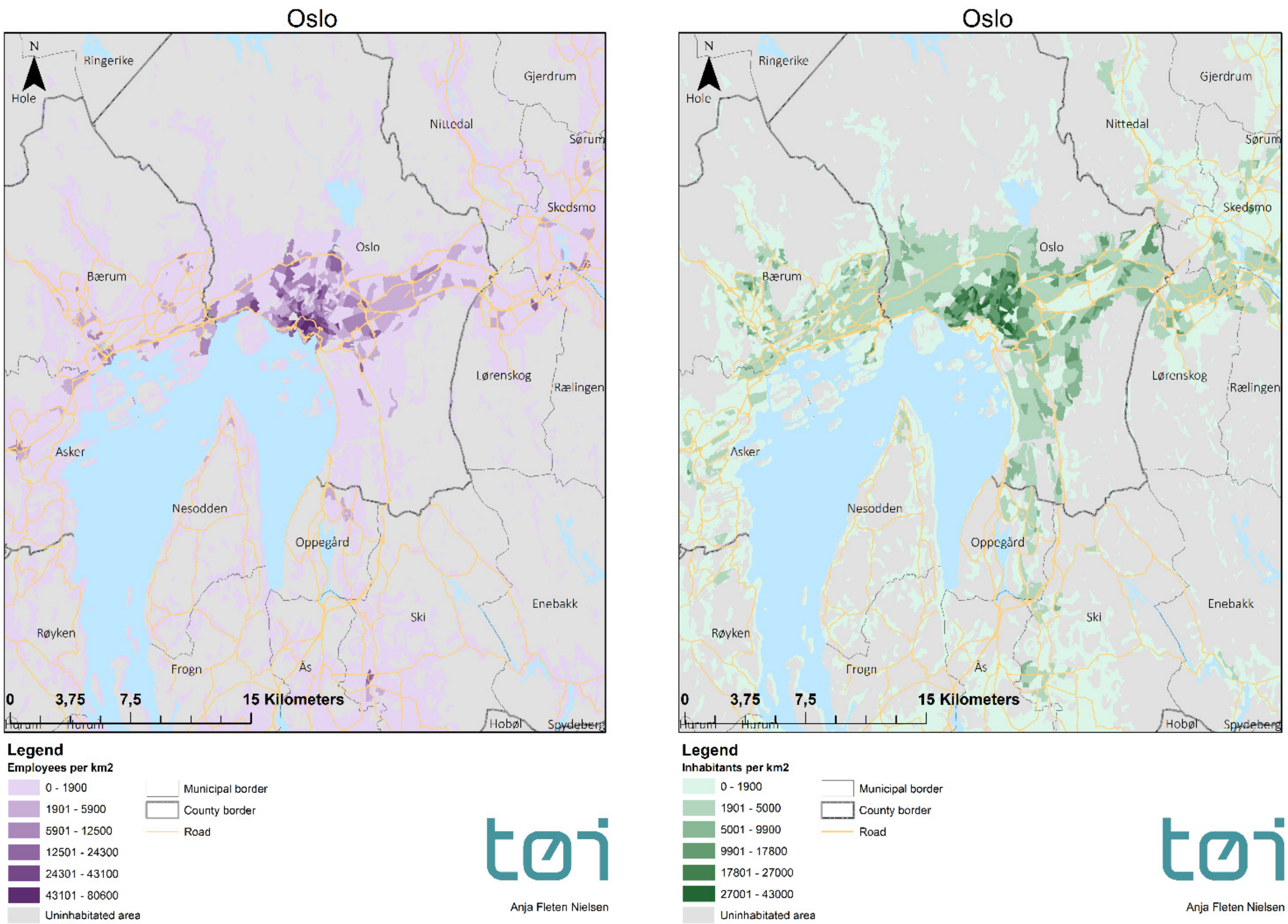

Figure 2. Job densities (to the left) and population densities (to the right) within different parts of Oslo metropolitan area
Source: Maps by Anja Fleten Nielsen, Institute of Transport Economics.

4 Methods

This paper is mainly based on the quantitative part of a study applying both qualitative and quantitative methods. The quantitative part consisted of a questionnaire survey among employees of 14 workplaces differently located within Oslo metropolitan area (Figure 3). With consent from the directors, administrative personnel at each workplace distributed electronic questionnaires by mail to the employees. At one workplace, research team members delivered paper versions of the questionnaire to employees passing by in the corridor at the canteen, since the directors at that workplace were not willing to distribute the questionnaire by mail.

We were thus only able to include respondents from workplaces where the managers accepted to let their employees participate and were willing to facilitate the process of questionnaire dissemination. Attaining permission from companies turned out more difficult than expected, particularly at workplaces within the municipality of Oslo. We sent invitation mails to all private and public-sector workplaces in the municipality of Oslo with more than 30 employees (close to 500 altogether) but only got acceptance from four workplaces.[1] In the suburban municipalities, employers were more willing to participate in the study. We thus succeeded in including an acceptable number of workplaces located at varying distance from the three second-order centers of Ski, Lillestrøm and Ås. Nevertheless, both in Oslo and in the neighboring municipalities, the participating workplaces were dominated by jobs requiring academic education. Only two workplaces with jobs predominantly requiring vocational education gave their consent to participate. In total, we received 1349 satisfactorily completed responses.[2]

Second-order and local centers within the metropolitan area were identified from a list of such centers applied in another, recent research project (Næss et al., 2019b). The different center categories were defined from relevant municipal and regional plans, information from Statistics Norway, a list of main transit nodes within the metropolitan area (Scheurer, 2014) as well as information about retail and local services available from internet maps. Distances (along a straight line) from each workplace to the city center of Oslo and lower-order centers, as well as commuting distances from respondents' dwellings to present and previous workplace were calculated using GIS in ArcMap. We also used this GIS source to calculate population and job densities around the respondents' present workplaces, where the density was calculated as the average density of the 250x250 m grid cell within which the workplace was situated and the eight adjacent cells, i.e., within a 750x750 m square approximately centered on the workplace. An index for transit accessibility was calculated for the respondents' workplaces. This index was based on the combined closeness and degree centrality of the closest among 96 transit nodes (Scheurer, 2014), adjusted for the Euclidean distance from the workplace to the transit node in question.

Apart from demographic and socioeconomic characteristics of the respondents, the questionnaire included questions about employees' commuting behavior, any errands carried out as part of the commute, reasons for choosing the workplace, acceptable commuting time, parking conditions at the workplace, car availability in the household for daily transport, and any access to company car. Information on workplace mobility, that is, whether the respondent had changed her workplace during the last three years, and if so, whether this had caused any changes in commuting distance or mode, was also collected. Reflecting the overrepresentation of "knowledge industries" among the investigated workplaces, persons with high income and particularly with long academic education are overrepresented among the respondents, compared to the population of the city region. Table 1 shows key demographic and socioeconomic characteristics of the respondents.

The qualitative part included 13 interviews with employees at eight of the investigated workplaces. We selected interviewees among the more than 450 questionnaire respondents who had volunteered for this task, aiming to include roughly the same number from workplaces in the municipality of Oslo and municipalities in outer parts of the urban region. The interviews were semi-structured, revolving around several pre-identified topics, and most often lasted between 35 and 40 minutes. The relatively short duration compared to interviews in our earlier studies on residential location and travel (see, e.g., Næss, Peters, Stefansdottir, & Strand, 2018; Næss, 2018) has to do with the narrower scope, concentrating on one single travel purpose (commuting).) Each interview was audio-recorded and fully transcribed. The main purpose of the interviews was explanatory (Næss, 2018), aiming to deepen the understanding that the quantitative part of the study had already suggested. However, we also tried to be open for new, previously overlooked issues. Each interview was therefore conducted in an open way, where the interviewees were first given the opportunity to speak freely for some minutes about their thoughts con-

[1] One of these workplaces (Oslo Science Park) included several separate companies clustered at the same location. The willingness among Oslo employers to participate in the study was substantially diminished as Oslo companies and public-sector entities had already been involved in a number of other questionnaire surveys on travel behavior in the year prior to our survey.

[2] We do not know the number of employees to which the questionnaire was sent at each workplace. The response rate therefore cannot be calculated.

cerning their choice of workplace and travel modes for commuting. Several interviewees had changed their workplace location and/or place of residence recently. The narratives of these interviewees about reasons for relocating, and the subsequent impacts of their relocations on travel, provided important information of how workplace location influences commuting. An interpretation scheme, developed in our earlier studies (see, for example, Næss et al., 2018) was used to structure the analysis of the interview material. Each interpretation was checked by one other research team member. (See Næss et al., 2019a, for further details.)

In addition to the 13 employees interviewed, we also carried out brief interviews with management representatives at nine of the workplaces. The topics addressed in these interviews included, among others, the degree of job specialization and the size of the catchment area for staff recruitment of each company.

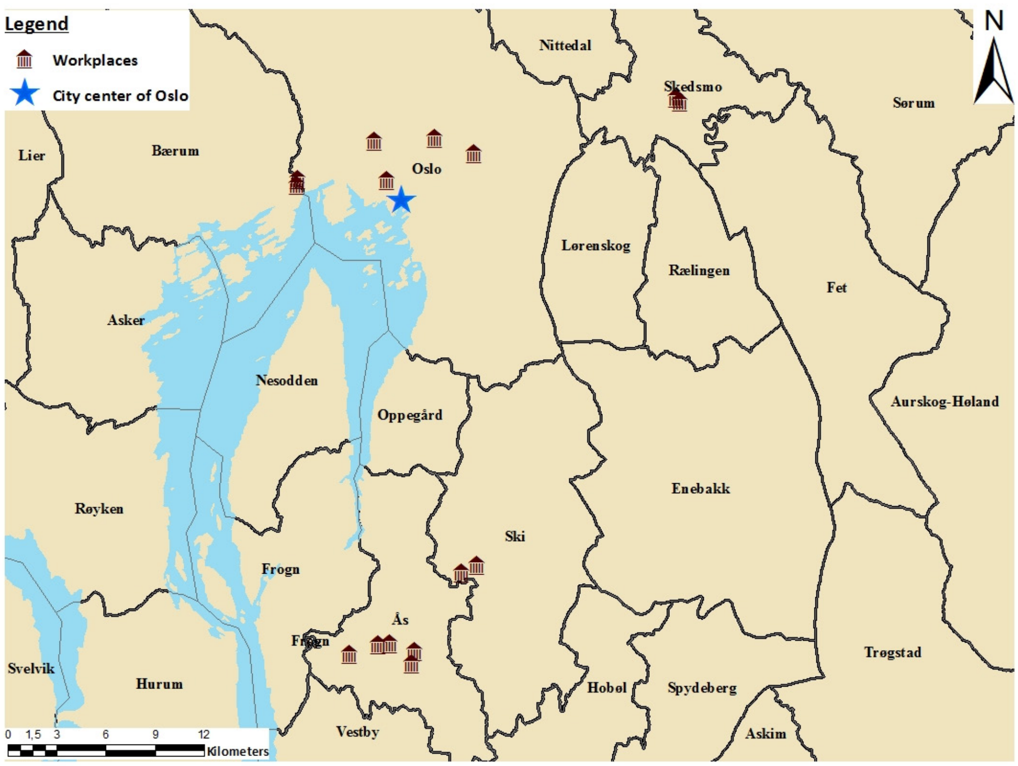

Figure 3. Location of investigated workplaces with blue asterisk indicating the city center of Oslo

Table 1. Comparison of demographic and socioeconomic characteristics of the survey respondents and averages for the counties to which Oslo metropolitan area belongs

	Survey respondents (N = 1097-1306)	Inhabitants of the counties Oslo and Akershus (including Oslo metro area)
Average number of persons per household	2.74	1.94
Average number of children aged 0 - 6 years per household	0.26	0.15
Average number of children aged 7 - 17 years per household	0.68	0.13
Average age of respondents/interviewees (all aged 16 or more)	46.1	45.5
Gender (proportion female)	55 %	50.3 %
Average annual personal income (1000 NOK)	681	577
Proportion with education at master level or higher	71 %	16 %
Average number of cars per household	1.22	1.18

5 Quantitative results[3]

5.1 Cross-sectional analysis

Based on our own work on the mechanisms contributing to different modal shares for commuting trips to central and peripheral workplaces (presented by figure 1) and earlier research on the relationship between land use and transport behavior, we specify multivariate models (multiple linear regression and logistic regression) to explore the associations between urban structure and commuting behavior. Variables representing commuting behavior investigated below include commuting distance, commuting mode, and commuting time.

5.1.1 Commuting distances

Figure 4 shows average one-way commuting distance associated with workplace locations at different distance belts from the city center of Oslo. Commuting distance tends to progressively increase the further workplaces are located away from the inner part of Oslo. On average, workplaces in the outer suburbs have mean commuting distances about 40% longer than those in the inner-city area.

[3] In all analyses in this section, respondents living more than 100 km away from the workplace they normally visit have been excluded from the analyses.

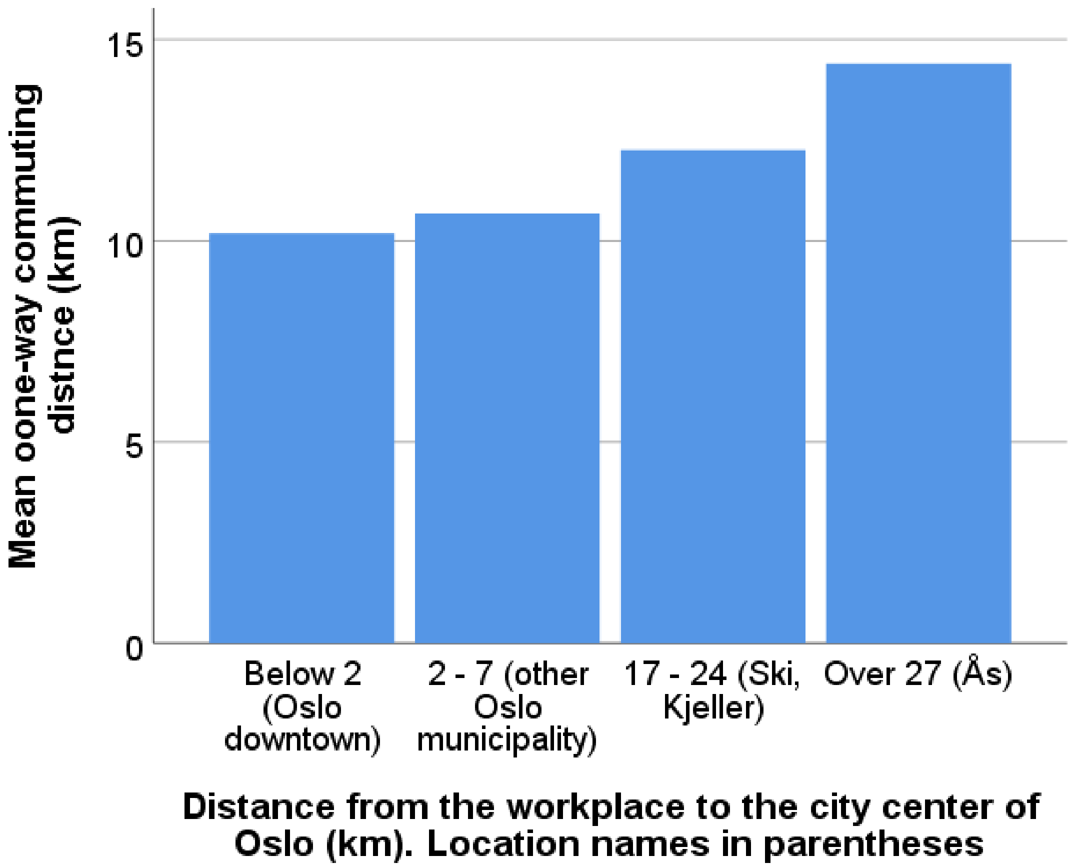

Figure 4. Mean commuting distances (measured by GIS) among employees of workplaces located at different distances from the city center of Oslo, N = 1306

To identify whether the gradient between center-periphery employment location and commuting distance is the result of employment distribution in the metropolitan structure or the result of other confounding influences, a multiple linear regression of commuting distance on urban structural variables and socio-demographics is modeled. Results in table 2 show that workplace location vis-à-vis the city center exerts the strongest influence. Workplace location with respect to the closest second order center is weakly significant. On the other hand, commuting distance appears to have no association with employment opportunities and population density at the neighborhood level.

Besides the built environment variables, higher income is associated with longer commuting distance whereas belonging to a household with other adult household members is associated with shorter commutes. Gender, age, education level and possession of driver's license for car have no effect, ceteris paribus.

Table 2. Variables associated with respondents' commuting distances

	Coefficients	P-value
Distance from workplace to the city center of Oslo	0.117 (0.091)	0.003
Distance from workplace to closest second-order center	1.046 (0.052)	0.073
Combined jobs and population density in workplace neighborhood (persons/hectare)	-0.0002 (-0.020)	0.580
Number of household members below 18 years	-0.5627 (-0.039)	0.184
Number of household members 18 years and above	-1.200 (-0.070)	0.010
Driver's license for car	1.8774	0.171
Gross annual personal income	0.529 (0.072)	0.013
Female	-0.8813	0.314
Age (mean centered)	-0.9633 (-0.016)	0.656
Long university education	1.1759	0.211
Constant	8.5197	0.000
Adjusted R^2	0.016	
Number of observations	1101	

Note: Estimated with robust standard error, standardized coefficients in parentheses

5.1.2 Travel modes

The dichotomy between central urban and suburban employment locations is even more dramatic when considering the proportion of commuters by car and by transit. Figure 5 shows the proportions of commuting regularly by car and by transit. Centrally located jobs account for a markedly smaller proportion of car commuters and a significantly higher proportion of transit commuters.

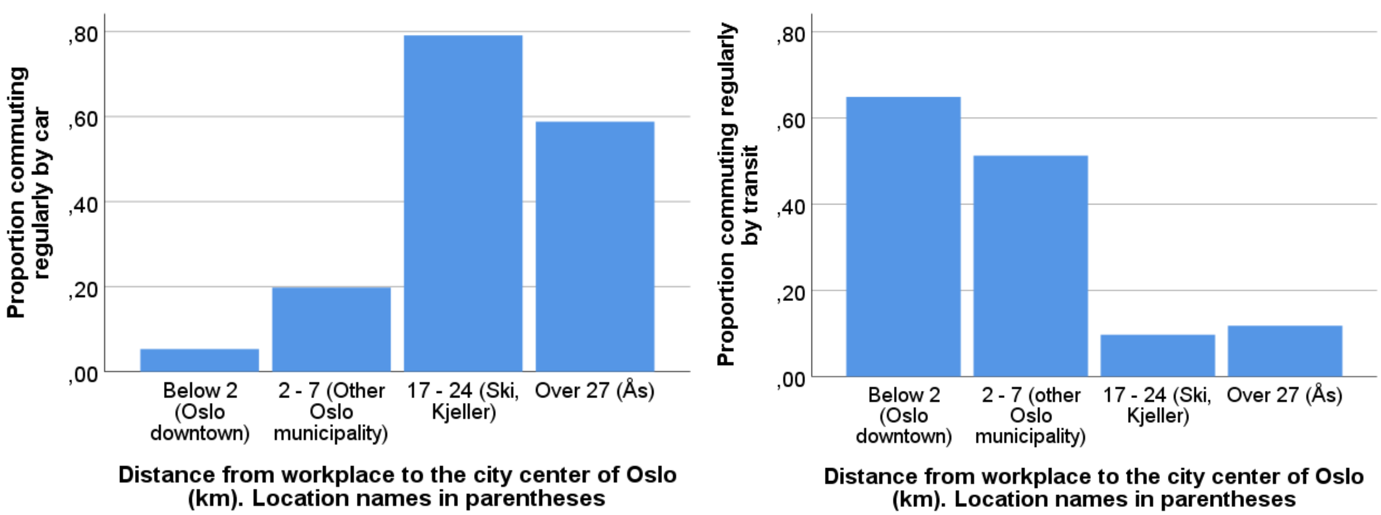

Figure 5. Proportions of employees commuting regularly for most of the commuting distance by car (to the left) and by transit (to the right) at workplaces located at different distances from the city center of Oslo, N = 1346

To decipher the contrasting patterns in commuting mode share between central urban and suburban employment locations, a multivariate relationship between the likelihood of commuting by a car/transit and urban structural variables is modeled using logistic regression. The multivariate model structure follows the causal mechanisms laid out in figure 1. The results (reported in tables 3a and 3b) show which ones among the urban structural variables are the most influential on commute mode choice after controlling for socio-demographics.

We run two separate logistic regression models for each mode, with each model progressively adding additional urban structure variables while controlling for socio-economic attributes. The first model (1) includes distance from center hierarchies as urban structure variables. The second model (2) adds Combined job and population density at workplace neighborhood, Job-population ratio and Index for transit accessibility at workplace on top of model 1. Table 3a reports model results for the likelihood of commuting by car while table 3b reports results for the likelihood of commuting by transit.

Results from model 1 show that distance of workplaces from the city center exerts the strongest influence while workplace distance from second-order centers is insignificantly associated with the likelihood of regularly commuting by car/transit. In model 2, combined jobs and population density in the workplace neighborhood as well as workplace distance from the city center are significantly associated with regularly commuting by car. Moreover, workplace distance from second-order center, which was insignificant in model 1, turns out as significant in model 2. This indicates that higher density in and around second-order centers is crucial for these centers to have any significant influence on reducing car commutes and increasing transit commutes. Another noteworthy result from model 2 is the reduction in effect size of workplace distance from the city center.

Urban structural variables are often highly correlated with each other, which makes interpreting the independent effect of individual variables somewhat tricky. As outlined in figure 1, metropolitan scale variables such as location of the workplace vis-à-vis the city center are likely to influence local-scale characteristics. Hence, the combined jobs and population density at workplace neighborhood is likely to partly reflect the influence of workplace distance from the city center.

In model 3, two more variables, namely population-to-jobs ratio and transit access at workplace location, are introduced. Both variables are insignificantly associated with commuting likelihood by car as well as by transit.

Table 3a. Variables associated with the likelihood of being a regular car commuter

	Model I		Model II	
	Coef.	**P-value**	**Coef.**	**P-value**
Distance from workplace to the city center of Oslo	0.0998 (0.447)	0.000	0.0701 (0.295)	0.000
Distance from workplace to closest second-order center	Insig.	0.831	0.3475 (0.093)	0.016
Combined jobs and population density in workplace neighborhood (persons/hectare)			-0.0008 (-0.325)	0.000
Index for transit accessibility at workplace*			Insig.	0.321
Population-job ratio in a 750mx750m grid cell			Insig.	0.707
Number of household members below 18 years	0.4226 (0.170)	0.000	0.4204 (0.159)	0.000
Number of household members 18 years and above	Insig.	0.372	Insig.	0.369
Driver's license for car	3.9186 (0.375)	0.000	3.9030 (0.351)	0.000
Gross annual personal income	0.0923 (0.072)	0.040	Insig.	0.167
Gender (Female=1)	0.3003 (0.059)	0.048	Insig.	0.128
Long university education	-1.2076 (-0.214)	0.000	-0.8183 (-0.136)	0.000
Age (mean centered)	0.9337 (0.089)	0.010	1.2575 (0.113)	0.000
constant	-7.4230	0.000	-5.8458	0.000
Number of observations	*1131*		1128	
Nagelkerke R^2	*0.418*		0.454	

Note: Estimated with robust standard error, standardized coefficients in parentheses; insig. = not significant at the 0.10 level. *Index for transit accessibility at workplace is computed in two steps. First, a harmonized average of closeness and centrality indices of the nearest transit node is calculated. Finally, the harmonized accessibility index is multiplied by the Euclidean distance from workplaces to the nearest node. Lower values of the index represent higher access.

Workplaces located in areas with higher combined job and population density tend to reduce the likelihood of commuting by car whereas those that are located further away from the city center tend to increase the likelihood of car commuting. Likewise, these same urban structural variables have significant influence on the likelihood of commuting by transit. Workplace distance from the city center reduces the likelihood of commuting by transit whereas higher combined job and population density at the workplace increases it. Looking at the standardized values of the two urban structural variables, combined jobs and population density appears to have a slightly stronger influence on the likelihood of commuting by car whereas workplace distance from the city center has relatively stronger influence on commuting likelihood by transit.

The insignificant effects of transit accessibility on car commuting as well as transit commuting partly reflects that the locations with highest transit accessibility are in dense districts close to the city center. The effects of transit accessibility are therefore largely absorbed by the density and distance to the city center variables. In addition, the central and dense areas are less accessible by car. Whereas the density and distance to the city center variables capture both the "pull" effect of high transit accessibility and the "push" effect of low car accessibility, the transit accessibility variable does not capture the latter effect. Our results imply that a high modal share for transit and a low modal share for car requires not only the "carrot" measure of high transit accessibility, but also the "stick" measure of difficult accessibility by car (as in the inner city of Oslo).

Higher number of household members below 18 years increases the likelihood of commuting by car while conversely reducing the likelihood of transit commuting. This reflects the need for easing time-geographical constraints. Moreover, men tend to be more likely to commute by car than women are, while there is insignificant difference between the genders in the likelihood of commuting by transit. Employees whose age is above the mean age (46 years) are more likely to commute by car whereas those below 46 year of age tend to be more inclined to commute by transit. Likewise, respondents who have a university education of at least four years have a lower likelihood of commuting by car and conversely a higher likelihood of commuting by transit.

Table 3b. Variables associated with the likelihood of being a regularly transit commuting

	Model I		**Model II**	
	Coef.	**P-value**	**Coef.**	**P-value**
Distance from workplace to the city center of Oslo	-0.1059 (-0.502)	0.000	-0.0743 (-0.346)	0.000
Distance from workplace to closest second-order center	Insig.	0.963	-0.5491 (-0.163)	0.003
Combined jobs and population density in workplace neighborhood (persons/hectare)			0.0005 (0.220)	0.000
Index for transit accessibility at workplace*			Insig.	0.248
Population-job ratio in a 750mx750m grid cell			Insig.	0.331
Number of household members below 18 years	-0.2935 (-0.125)	0.000	-0.3042 (-0.127)	0.000
Number of household members 18 years and above	Insig.	0.484	Insig.	0.864
Driver's license for car	-2.0268 (-0.205)	0.000	-2.0625 (-0.205)	0.000
Gross annual personal income	-0.0911 (-0.075)	0.044	Insig.	0.197
Gender (Female=1)	Insig.	0.161	0.2726 (0.055)	0.098
Long university education	0.7971 (0.149)	0.000	0.5038 (0.093)	0.013
Age (mean centered)	-1.8090 (-0.183)	0.000	-2.1310 (-0.212)	0.000
constant	4.5630	0.000	3.5484	0.000
Number of observations	*1131*		*1128*	
Nagelkerke R^2	*0.422*		*0.438*	

Note: Estimated with robust standard error, standardized coefficients in parentheses; Insig. = not significant at the 0.10 level.
*Index for transit accessibility at workplace is computed in two steps. First, a harmonized average of closeness and centrality indices of the nearest transit node is calculated. Finally, the harmonized accessibility index is multiplied by the Euclidean distance from the workplaces to the nearest node. Lower values of the index represent higher access.

The proportion of commuters who regularly travel by non-motorized modes for the longest part of the commute also reflects the urban structural conditions and the vulnerabilities of active travel. Figure 6 shows the proportion of walking/biking for the longest part of the commute with respect to employment location from the city center. Generally, the proportion of walking as a commuting mode sharply declines as distance of employment location from the city center increases. In inner part of Oslo, where proximity between facilities is high, the built environment is more conducive for walking. Biking is likely to be somewhat curtailed in this part of the city due to high pedestrian flow and congested streets and safety issues. In the area of the city between 2 and 7 kilometers from the city center, the land-use type is predominantly residential. At this location a range of workplaces are out of walkable range but within range for bikers. Besides, this region of the city does allow for many alternative streets that are less congested.

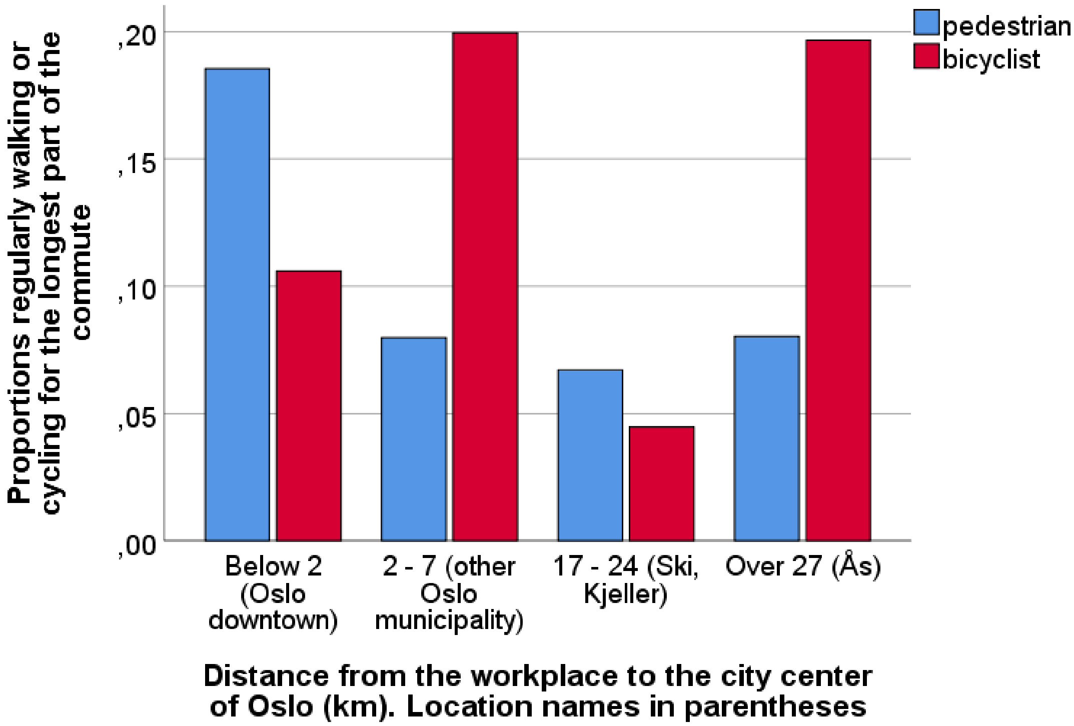

Figure 6. Proportions of employees commuting regularly for most of the commuting distance as pedestrian (blue) and as bicyclist (red) at workplaces located at different distances from the city center of Oslo, N = 1346

5.1.3 Commuting time

Even though centrally located jobs can lead to reduced commuting distances, this may not necessarily equate to reduced commuting time. Figure 7 shows that employment locations in the central parts of Oslo contribute to longer commuting time compared to employment locations in the outer parts of the metropolitan areas.[4] This is as expected. Commuting by public transport involves access-egress time, waiting time at transit stops and changing time between modes. Transit commute often requires multiple stops with considerable time spent on embarking and disembarking passengers. Sharing streets with all traffic modes also slows down the traffic flow of motorized transport. Moreover, streets are narrower and traffic-calming measures are more prevalent in the central areas of cities, and Oslo is no different. Some previous finding from American studies found that dispersed spatial structures were associated with shorter commuting times (Gordon & Lee, 2015; Gordon et al., 1989; Gordon, Richardson, & Jun, 1991; Levinson & Kumar, 1994). These findings are often conflated with reduced commuting distance. Shorter commuting times in the outer parts of the metropolitan areas does not mean that commuting distances are also shorter in these areas.

[4] A multivariate analysis shows the following standardized coefficients and significance levels (in parenthesis) for the effect of built environment variables on commuting time: Distance from workplace to the city center of Oslo = -0.184 (0.000), population density per hectare = 0.083 (0.006) and population-job ratio=-0.057 (-0.057).

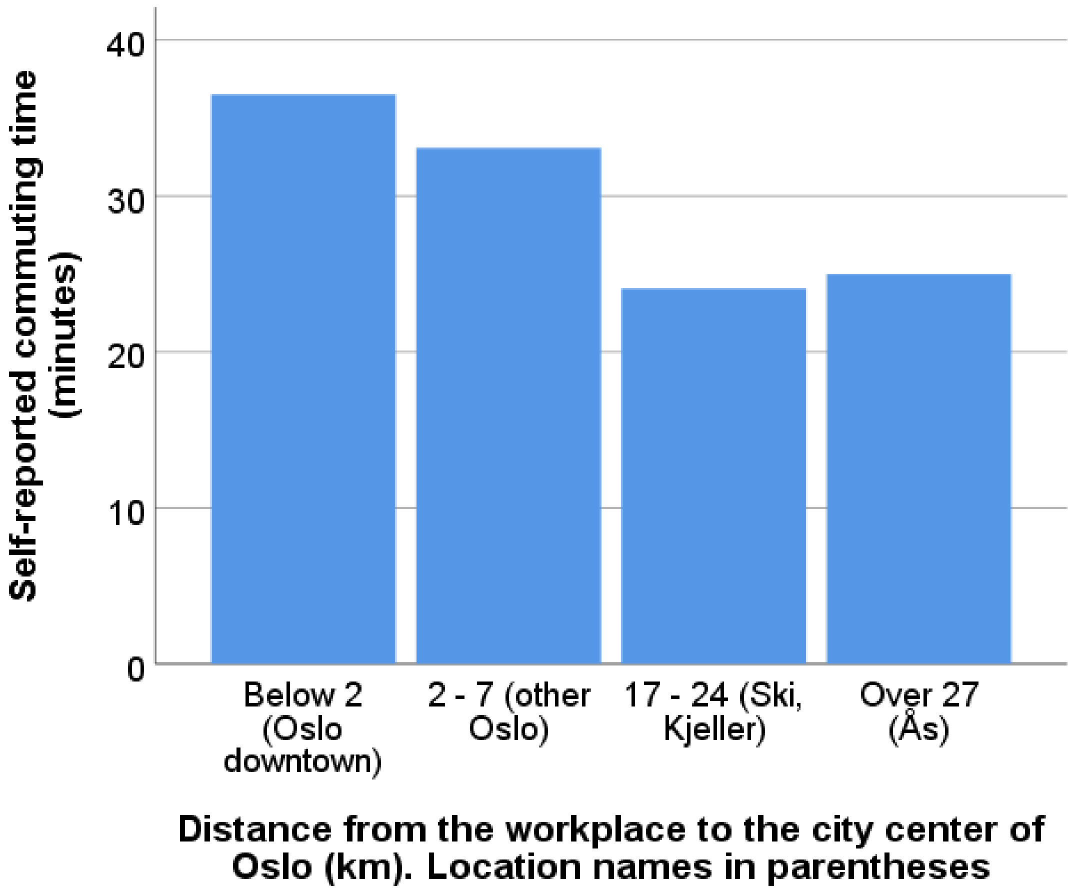

Figure 7. Mean commuting time (self-reported) among employees of workplaces located at different distances from the city center of Oslo, N = 1346

5.2 Changes after moving

Cross-sectional analysis is often criticized for its weakness in accounting for person specific differences that could have influenced the observed outcome. To lend credence to the results discussed so far, a semi-longitudinal analysis is modeled below, showing how change in urban structural variables resulting from change in job location influences commuting mode choice. Our questionnaire survey asked respondents whether they had changed their workplace location during the last three years. For those who had moved to a new workplace, we asked about the address of the previous workplace and whether moving from their previous to their present workplace had caused any change in their mode of transportation between home and workplace. A similar question was asked about commuting distance.

In line with the theoretical considerations discussed in Section 2.1, we expected to find a tendency of more frequent car commuting and less frequent transit commuting among respondents whose new workplace was more peripherally located than the previous one, and opposite tendencies among respondents who had shifted to a more central job location. We also expected to find similar, but weaker tendencies on commuting distances, with outward relocation associated with longer and inward relocation with shorter commutes.

Table 4 shows the likelihood of change in travel behavior by a given mode because of change in urban structural factors (distance from workplace to the city center of Oslo, distance from workplace to closest second-order center and job density per hectare at workplace) following job relocation. Employees who relocated to workplaces further away from the city center have a significantly higher likelihood of commuting more often by car than before the move. Regarding transit commutes, the opposite holds true. Job relocation closer to the city center of Oslo significantly increases the likelihood of increased commuting by transit.

Job relocation away from the closest second-order center is also significantly associated with increased likelihood of commuting by transit, which appears counterintuitive. However, within Oslo metropolitan area, moving away from the closest second order center in many instances means moving inwards and closer to the center of Oslo. This is especially true for employment location in the outer areas of the metropolitan region. The third variable in the table, neighborhood-scale job and population density at the workplace is poorly associated with increase/decreased incidence of commuting by any given mode.

Table 4. Variables associated with the likelihood of having changed one's frequency of car commuting and transit commuting due to workplace relocation

	Commuting by car more often	Commuting by transit more often
Increase in distance from workplace to the city center of Oslo	0.0860	-0.0855
	0.620	*-0.571*
	(0.000)	**(0.000)**
Increase in distance from workplace to closest second-order center	-0.1261	0.1420
	-0.177	*0.185*
	(0.356)	**(0.037)**
Increase in job density (persons/hectare) in workplace neighborhood	-0.0003	0.0017
	-0.037	*0.226*
	(0.696)	(0.220)
Constant	-1.4196	-1.0242
	(0.000)	(0.001)
Nagelkerke R^2	0.359	0.374
Number of observations	114	114

Note: Estimated with robust standard error, standardized coefficients in italics and P-values in parentheses; significance levels $p < 0.05$ are highlighted in bold.

Distinct from travel modes, we found only a weak and rather uncertain effect of job relocation on self-reported changes in recent movers' commuting distances (table not shown). Contrary to the results of the cross-sectional analyses, respondents relocating to a more peripheral workplace tended to reduce their commuting distance slightly ($p = 0.073$). There was, however, no corresponding tendency of increased commuting distance among respondents who changed to a workplace closer to the city center. One possible explanation of the diverging result compared to the GIS-based cross-sectional analysis could be that some respondents may have conflated commuting distance with commuting time. As shown in Figure 7 above, commuting time tends to be lower for employees at peripheral workplaces than among those working centrally.

6 Why does suburban workplace location tend to increase car commuting?

Interviewees' transport rationales, i.e., their backgrounds, motivations and reasons for location of activities and travel modes, are important links in the causal links by which workplace location influences commuting distances and modes (Næss et al., 2018).

6.1 Rationales influencing commuting distances

In line with findings in previous studies (Næss, 2005, 2013; Næss et al., 2018), two main rationales influence the interviewees' choices of workplace location: choosing the "best facility" (mainly expressed in terms of job contents) and *limiting the "friction of distance"* (most often expressed in terms of travel time). All thirteen interviewees emphasize job content as the key attractiveness criterion for a job opportunity, sometimes specified to mean that it must match the interviewee's educational qualifications or skills from work experience. Some interviewees also mention good colleagues/work environment as an additional criterion, whereas only a few interviewees mention the salary level. Interviewees who regularly bring and pick up children at kindergarten or school tend to place greater emphasis on limiting travel time than interviewees without such responsibilities. For the remaining interviewees, choosing the best job content is clearly more important than minimizing travel time, reflected in quite high levels for acceptable commuting time.

Most of the interviewees attach strong importance attached to the *"best facility"* rationale and therefore rather travel a bit further if they can then find a more attractive job. The job seeker must also be selected by the employer in competition with other applicants. This double requirement – that the applicant must find the job attractive at the same time as the employer must find the applicant worth hiring – implies that the number of workers as well as jobs must be high in a local district to make local employment a likely outcome, particularly if the job requires specialized skills. Commuting distances therefore depend more on the location of the workplace relative to large concentrations of dwellings than on the distance to the closest residential neighborhood, at least for workers with specialized qualifications. Because population densities are considerably lower in the outer than in the inner and central parts of the urban region, the likelihood for a suburbanite to be employed at a local suburban workplace is not very high. On the other hand, workplaces close to the city center have a large number of potential employees within a short distance from the workplace and are therefore more likely to recruit workers locally. For workplaces with predominantly non-specialized jobs (such as primary and secondary schools, kindergartens, non-specialized stores, warehouses etc.), the likelihood of recruiting local employees is higher, also in the suburbs, since applicants for such jobs will more often find the local job opportunities to be as attractive as more distant ones.

Our interviews showed an example where one of the spouses of a dual-earner household was able to get a job in a small town at the metropolitan fringe where the other spouse was already working. This induced them to move from their earlier, more centrally located home to a residence near her new job. This was still rather atypical. More often, moving closer to one spouse's peripheral workplace would imply a longer commute for the other spouse.

6.2 Rationales influencing commuting travel modes

For twelve of the thirteen interviewees, *time-saving* is either the dominant or one of two equally important rationales. The emphasis on time-saving as a rationale for travel mode choice appears to be especially strong among interviewees with long commuting distances. *Limiting travel* expenses is a rationale of importance to some interviewees, influencing their travel mode either directly or indirectly by affecting their car ownership. *Convenience/easiness of travel* is a travel mode choice rationale encountered in several interviews, closely related to a rationale of *flexibility*. For some interviewees, a wish for *physical exercise* during the commute exerts some influence on their travel mode choice. For a few interviewees, *affective dislike* of a certain travel mode restricts their commuting mode choice. *Social contact/communication* and *caretaking* affect the travel mode choices of a few interviewees who drive together with their spouses to work or bring teenagers to activities in connection with the journey home from work. A *safety* rationale is encountered in a couple of interviews, working as a disincentive against biking. Finally, five rationales for commuting mode choice are encountered in only one interview each: Stress avoidance, frustration aversion, control and predictability, obligation and environmental concerns.

Of the eleven rationales for commuting mode choice identified in the interviews, six contribute more or less strongly to make car driving the most attractive travel mode when commuting to suburban workplaces and transit or non-motorized modes the most attractive ones when commuting to centrally located workplaces. Three of these six rationales (time-saving, convenience and flexibility) trigger quite strong mechanisms inducing employees of suburban workplaces to choose car as their commuting mode whereas employees at central workplaces are induced to commute by transit or non-motorized modes. These three rationales, and particularly time-saving, are at the same time the rationales encountered most frequently among the interviewees. The rationale of limiting travel expenses works in the same direction. Two other rationales also contribute to the typical differences between employees of suburban and central workplaces in commuting modes, although encountered in fewer interviews: avoidance of stress and frustration, and predictability and control.

None of the five remaining rationales tends to counteract the differences between central and suburban workplaces in typical travel modes. The physical exercise rationale can motivate non-motorized travel in inner-city as well as suburban situations, depending on the specific context (availability of bike paths/lanes, sidewalks, pleasantness of the route environment, etc.). Similarly, the safety rationale can discourage non-motorized commuting (especially biking) to central as well as suburban workplaces, depending on the infrastructure and traffic volume along relevant routes. Finally, three rationales (social contact, caretaking and affective dislike) appear to influence the interviewees' travel modes in the same ways regardless of workplace location.

7 Discussion

Among the employees of the sixteen investigated workplaces, commuting distances tend to increase the further away from the city center of Oslo the workplace is located. Although relatively high proportions of the employees of the most peripheral workplaces live at a short distance from their jobs, this is outweighed by long commutes among the remaining employees. In total, commuting distances are therefore more than 40% longer among the respondents working at the most peripheral workplaces (in Ås) than among those working in the inner city of Oslo. The longer commutes to suburban jobs imply that the tendency of shorter commuting distances to centrally located workplaces resulting from the high population density in inner-city areas is stronger than the counteracting tendency for suburbanites who emphasize minimizing of friction of distance to seek employment at the available peripheral workplaces.

A similar overall pattern of longer commutes among employees of peripheral workplaces has been found in earlier studies (Cervero & Landis, 1992; Hartoft-Nielsen, 2001, focusing on office workplaces; Strømmen, 2001; Schwanen et al., 2001; Yang, 2005; Engebretsen et al., 2018). Some other studies have found the average commuting distances to centrally located workplaces to differ little from those to workplaces at the urban fringe (Crane & Chatman, 2003; Guth et al., 2009; Næss, 2007). In the latter study, average commuting distances in Copenhagen metropolitan area were found to increase somewhat with increasing workplace distance from the city center within the range covered by the present study (up to 28 km), but then decreased as the distance from the city center increased beyond this level. Moreover, while the commuting distances of workers with a long university education tended to increase the further from the city center the workplace was located, an opposite pattern was found among respondents without such education. Given the large proportion of respondents with long university education in the present study, our results appear consistent with those of the Copenhagen metropolitan area study.

The commuting travel modes to our investigated central workplaces differ sharply from those to the peripheral workplaces, with much higher shares of car commuting and much lower shares of commuting by transit to workplaces located far away from the city center. This reflects the easier driving conditions, poorer transit accessibility and usually ample parking opportunities typical for suburban workplaces, and the high transit accessibility, scarce or expensive parking and peak-period congestion typical for centrally located workplaces and their surroundings. In combination with the rationales for travel mode choice found among our interviewees (particularly time-saving, convenience and flexibility, but also limitation of economic expenses, avoidance of stress/frustration and predictability/control) these conditions can explain the observed very different commuting mode profiles of central and peripheral workplaces. The overall share of non-motorized commuting does not vary much along the center-periphery gradient, but looking at walking and biking separately, we find an interesting pattern where employees of inner-city workplaces tend to use walking while their counterparts at suburban workplaces tend to prefer cycling as their non-motorized mode. This reflects the more congested streets, density of traffic lights and low provision of bike lanes in the inner city which, combined with rationales of safety and stress/frustration aversion, make biking less attractive to centrally located jobs.

The higher shares of transit commuting and lower shares of car commuting to centrally located workplaces are in line with findings in a number of earlier studies in Scandinavia and elsewhere (Monsen, 1983; Cervero & Landis 1992; Hanssen, 1995; Martamo, 1995; Næss & Sandberg, 1996; Hartoft-Nielsen, 2001; Schwanen et al., 2001; Strømmen, 2001; Yang, 2005; Næss, 2007; Aguiléra et al., 2009; Aguilera & Voisin, 2014; Hartoft-Nielsen & Reiter, 2017; Hu & Schneider, 2017; Engebretsen et al., 2018; Næss et al., 2019b). Together with the on average longer commuting distances to suburban workplaces, this translates into substantially higher energy use for commuting and related CO_2 emissions if the workplace is located in the suburbs than if it is located in the inner city. Among our respondents, the average energy use and CO_2 emissions among respondents working more than 17 km from the city center is three times higher than among those working less than 2 km from the city center.[5]

Do the above results mean that there is no sustainable mobility benefit from locating workplaces in suburban center in line with the polycentric model for urban development? We do find tendencies of lower shares of car commuting and higher shares of transit commuting if the workplace is located close to second-order centers such as Lysaker, Lillestrøm, Ski and Ås. However, these effects are much weaker than those of the distance to the main city center. Workplace location in compact, transit-oriented centers does perform better, judged from a sustainable mobility perspective, than ordinary outward urban spatial expansion does. However, polycentric workplace development is far less favorable than densification close to the main city center if the aim is to reduce car driving and promote public and non-motorized commuting modes.

8 Concluding remarks

Our material shows a strong tendency of higher shares of car commuting among employees at suburban workplaces, who also commute longer distances on average than their counterparts working in the inner city. For the kind of jobs dominating at the 14 investigated workplaces, a central location is thus favorable from the perspective of reducing car driving for commuting. Conversely, job decentralization within a metropolitan area tends to increase car commuting both in terms of modal share and driving

[5] Mean daily CO_2 emissions for respondents working less than 2 km from the city center and more than 17 km from the city center are 1.117 kg and 3.367 kg, respectively, based on emission factors for different travel modes and adjusted for each respondent's weekly number of days at the workplace. Emission factors taken from http://www.gronnhverdag.no/nor/Transport/CO2-utslipp-fraforskjellige-transportmidler, accessed February 2018.

distances, also if the workplaces are located in transit-oriented suburban nodes. Even with good transit connections, such nodes can hardly match the inner city in terms of transit accessibility. If the workplaces recruit employees from other transit line corridors than the main corridor in which the workplace in question is located, employees living elsewhere will often need to change between different transit lines, which adds to travel time and is normally perceived as negative. Even more importantly, access by car is nearly always easier to suburban centers than to the main city center. On the other hand, the capacity of inner cities to increase the number of workplaces is limited, and very heavy job densification in these areas may easily conflict with heritage concerns, reduce urban green areas and compete with the wish for more inner-city dwellings (which is also favorable from a sustainable mobility perspective). For new workplaces that cannot be accommodated within the urban fabric of the inner city, job densification in the strongest suburban transit nodes is a relevant strategy. However, if such workplace location is to contribute to less car driving, deterrents such as reduced parking availability, parking fees, local road pricing, narrower streets and traffic signal priority for transit must be introduced to level out some of the car accessibility difference between the inner city and suburban centers. Otherwise, the belief in reducing car commuting by locating more jobs to suburban transit nodes will be an illusion.

In order to promote its goals of sustainable mobility, the next revision of the regional plan should allocate most of the growth in high-specialized jobs to the parts of Oslo easiest accessible by transit. The present aim for growth in these kinds of workplaces in the sub-regions northeast and southeast of Oslo should thus be abandoned.

However, not all kinds of workplaces should be centrally located. Kindergartens, schools, grocery stores and other non-specialized functions are examples of facilities serving local communities and for which the number of users/visitors is normally much higher than the number of employees. Such facilities should be located in the neighborhoods they are intended to serve, preferably in a local center with good transit accessibility. Some workplaces are also of a kind requiring a large plot area per employee (for example, warehouses and many kinds of manufacturing), and often they also generate much goods transport. Such workplaces should of course not occupy precious inner-city space and burden the narrow inner-city streets with truck traffic. In line with the Dutch ABC principle for environmentally friendly workplace location (Verroen, Jong, Korver, & Jansen, 1990), such industries should rather be located in the suburbs close to major intercity transport arteries, yet with acceptable transit accessibility for the workers.

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